

# FUNCTIONAL RELATIONSHIPS FOR $T_{\text{eff}}$ AND $\log g$ IN F-G SUPERGIANTS FROM $uvby\beta$ PHOTOMETRY

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Received July 7, 2010; accepted July 7, 2010

## RESUMEN

A partir de datos fotoeléctricos en el sistema  $uvby\beta$  y de valores precisos sintéticos y espectroscópicos de  $T_{\text{eff}}$  y  $\log g$  en 50 supergigantes de tipos espectrales F-G, hemos calculado relaciones funcionales que permiten la estimación inicial de la temperatura efectiva y la gravedad en este tipo de estrellas. Se demuestra que aunque las calibraciones de  $T_{\text{eff}}$  fueron calculadas con los datos de estrellas supergigantes jóvenes y masivas, también son válidas para estrellas evolucionadas post-AGB y RV Tau de temperaturas similares. La gravedad superficial también puede calcularse a partir del índice  $\Delta[c_1]$  con una precisión de 0.26 dex. Aunque se puede distinguir una correlación entre  $M_V$  y  $\Delta[c_1]$ , no hemos encontrado una correlación que prediga  $M_V$  de manera suficientemente precisa.

## ABSTRACT

From photoelectric  $uvby\beta$  data and recent accurate synthetic and spectroscopic values of  $T_{\text{eff}}$  and  $\log g$  for 50 F-G supergiants, we have calculated functional relationships that lead to initial estimates of effective temperature and gravities for these types of stars. It is shown that while the  $T_{\text{eff}}$  relationships are calculated using the data on young massive supergiants, they are also valid for evolved stars of similar temperatures like post-AGB and RV Tau stars. The gravity can also be predicted from the  $\Delta[c_1]$  index with an uncertainty of about 0.26 dex. Although a clear and significant trend between  $M_V$  and  $\Delta[c_1]$  is seen, no calibration is found that predicts accurate values of  $M_V$ .

**Key Words:** STRÖMGREN PHOTOMETRY - SUPERGIANT STARS - POST-AGB STARS

## 1. INTRODUCTION

Back in the mid 1990's we had calculated a set of functional relationships between several reddening-free indices in the Strömgren  $uvby\beta$  system and the effective temperature for 41 supergiants of luminosity classes I and II and with spectral types between A0 and K0. The main goal of those relationships was to provide initial values of the effective temperature for our own spectroscopic work aimed to calculate detailed atmospheric abundances for stars of intermediate temperatures. At that time we used the temperatures calculated by Bravo-Alfaro et al. (1997) from 13-color photometry and the  $uvby\beta$  data from the catalogue of Arellano Ferro et al. (1998).

The relationships turned out to be quite useful for several problems related to the estimation of the

temperature for these types of stars. However they remained unpublished mainly because the intrinsic scatter was rather large, probably due to the limited quality of the temperature data used.

Very recently a set of accurate temperatures, gravities and distances for 48 near ( $d \leq 700$  pc) and 15 distant ( $d \geq 700$  pc) A-G supergiants, were published (Lyubimkov et al. 2010). In the present paper functional relationships are worked out in the light of these new values of physical parameters with the aim to provide a tool to estimate initial values of  $T_{\text{eff}}$  and  $\log g$  in yellow supergiants for subsequent spectroscopic work.

The paper is organized as follows: in § 2 the sources of the  $uvby\beta$  data are described, in § 3 the calibrations for the temperature as a function of the  $[c_1]$ ,  $[m_1]$  and  $H\beta$  photometric indices are discussed, in § 4 the gravity calibration in terms of the  $\Delta[c_1]$  index is calculated, in § 5 we discuss the validity of

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the calibrations for post-AGB and RV Tau stars, in § 6 the attempts of a calibration of the absolute magnitude and its limitations are presented and in § 7 we summarize our conclusions.

## 2. THE PHOTOMETRIC $uvby\beta$ DATA

The  $uvby\beta$  photometric data have been taken from the catalogue of Arellano Ferro et al. (1998). For about a dozen of stars photometric data are not available in that source and their data have been obtained from the sources given in the Simbad database. When several measurements exist a simple average was calculated. In Table 1 we present for the sample stars their reddening free indices  $[c_1] = c_1 - 0.16(b - y)$  and  $[m_1] = m_1 + 0.33(b - y)$ , and their values of distance, effective temperature and gravity taken from Lyubimkov et al. (2010).

## 3. THE $T_{\text{eff}}$ CALIBRATIONS

Plots of  $T_{\text{eff}}$  as a function of  $[c_1]$  and  $[m_1]$  are shown in Figs. 1 and 2 respectively. Variable, double and non-variable stars have been plotted with different symbols to check if their nature contributes to the scatter or if they appear as outliers. For the variable stars we used averages from rather scarce photometry not covering the full variational cycles, despite of which they follow the trends as well as the non-variable and double stars.

The  $T_{\text{eff}}-[c_1]$  correlation is good for F-G type stars. Five A-type stars included in the sample of Lyubimkov et al. (2010); HR 825, HR 1740, HR 2874, HR 3183 and HR 6081 are identified as open circles and the K1 star HR 461 (Yoss 1961) were not included in the fit. The line has the form:

$$T_{\text{eff}} = 1566.6(\pm 50.7)[c_1] + 4704.0(\pm 40.5), \quad (1)$$

where the standard deviation is 152 K and the correlation coefficient is  $R = 0.98$ .

We can confirm from the models of Lester, Gray & Kurucz (1986) that the  $c_1$  index is temperature sensitive for  $T_{\text{eff}} \leq 7000$ K and that for hotter stars the sensitivity of the index changes and becomes more gravity dependent. This explains why the A-type stars do not follow the smooth correlation displayed by the F-G stars.

The  $T_{\text{eff}}-[m_1]$  correlation shows a non-linear form that can be represented by:

$$T_{\text{eff}} = 6081.3(\pm 817.0)[m_1]^2 - 9294.9(\pm 731.8)[m_1] + 8486.7(\pm 149.5). \quad (2)$$

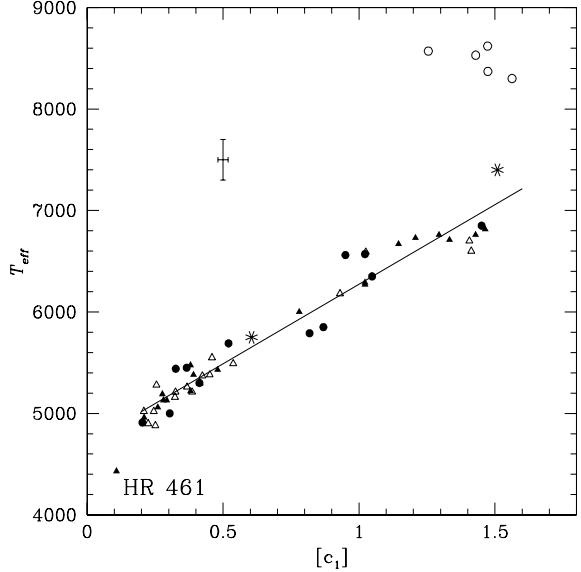


Fig. 1. Temperature dependence of the reddening free  $[c_1]$  index. The open circles correspond to five A type stars which along with the K1 star HR 461 are not included in the fit. The fit is valid for F-G type stars. Filled circles represent variable stars, empty triangles double stars and filled triangles non-variables. Asterisks correspond to two possible post-AGB stars in the sample of Lyubimkov et al. (2010). The error bars correspond to typical uncertainties of  $\pm 200$ K and  $\pm 0.019$  mag in  $T_{\text{eff}}$  and  $[c_1]$  respectively.

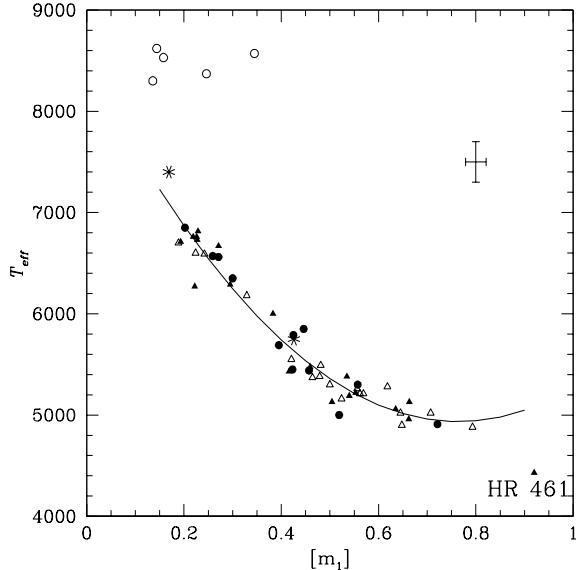


Fig. 2. Temperature dependence of the reddening free  $[m_1]$  index. Symbols are as in Fig. 1. The error bars correspond to typical uncertainties of  $\pm 200$ K and  $\pm 0.021$  mag in  $T_{\text{eff}}$  and  $[m_1]$  respectively.

TABLE 1

PHYSICAL PARAMETERS AND PHOTOMETRIC INDICES FOR THE SAMPLE F-G SUPERGIANTS.

Star	D (pc)	$T_{\text{eff}}$ (K)	$\log g$ (dex)	$[c_1]$	$[m_1]$	$H\beta$	$E(b - y)$	$M_V$	$\Delta[c_1]$	Sp.T.	Comment
HR27	380.	6270.	2.10	1.022	0.222	2.668	0.100	-3.3	-0.236	F2 II	
HR 157	259.	5130.	2.15	0.293	0.504	2.585	-0.031	-1.5	-0.130	G2.5 IIa	
HR 207	935.	5220.	1.55	0.380	0.145	2.626	0.553	-3.9	0.000	G0 Ib	
HR 792	397.	5020.	2.09	0.245	0.645		0.034	-1.8	-0.062	G5 II	D
HR 849	538.	5020.	1.73	0.209	0.707	2.605	0.019	-8.6	-0.068	G5 Iab:	D
HR 1017	156.	6350.	1.90	1.048	0.300	2.681	0.097	-5.1	0.114	F5 Ib	V,S
HR 1135	170.	6560.	2.44	0.950	0.271	2.684	0.046	-2.6	-0.093	F5 II	V,RRL
HR 1242	629.	6815.	1.87	1.464	0.229	2.730	0.310	-5.3	0.236	F0 II	
HR 1270	427.	5060.	1.91	0.260	0.635	2.580	0.045	-2.1	-0.050	G8 IIa	
HR 1303	275.	5380.	1.73	0.451	0.479	2.609	0.097	-3.5	-0.018	G0 Ib	D,SB
HR 1327	98.	5440.	2.89	0.326	0.457	2.574	-0.024	+0.4	-0.183	G5 IIb	S
HR 1603	265.	5300.	1.79	0.414	0.500	2.607	0.002	-0.6	-0.009	G1 Ib-IIa	D
HR 1829	49.	5450.	2.60	0.366	0.423	2.576	0.007	-0.6	-0.232	G5 II	S
HR 1865	680.	6850.	1.34	1.451	0.202	2.730	0.121	-7.1	0.086	F0 Ib	V,S
HR 2000	224.	5000.	2.45	0.304	0.519	2.568	-0.045	-0.4	-0.105	G2 Ib-II	S
HR 2453	633.	4900.	1.70	0.224	0.648	2.582	-0.033	-2.4	-0.083	G5 Ib	D
HR 2597	935.	6710.	2.00	1.333	1.777	2.721	0.193	-4.3	-0.071	F2 Ib-II	
HR 2693	495.	5850.	1.00	0.869	0.446	2.660	0.013	-6.7	0.337	F8 Ia	V,S
HR 2786	386.	5260.	1.90	0.367	0.556	2.619	0.003	-2.7	-0.003	G2 Ib	D,S
HR 2833	375.	5380.	2.21	0.391	0.535	2.586	-0.010	-1.8	-0.005	G3 Ib	
HR 2881	461.	5300.	1.66	0.413	0.557	2.622	-0.029	-3.6	0.042	G3 Ib	S
HR 3045	370.	4880.	1.21	0.251	0.793	2.625	-0.030	-4.4	0.000	G6 Ia	D,S
HR 3073	338.	6670.	2.61	1.145	0.271	2.700	0.080	-2.2	0.106	F1 Ia	
HR 3102	161.	5690.	2.17	0.520	0.395	2.651	-0.005	-1.8	-0.144	F7 II	S
HR 3188	325.	5210.	1.75	0.325	0.569	2.589	-0.026	-3.1	-0.035	G2 Ib	D
HR 3229	267.	5130.	2.04	0.281	0.663	2.584	-0.003	-2.1	-0.016	G5 II	
HR 3291	900.	6600.	1.25	1.413	1.996	2.703	0.224	-7.2	0.165	F3 Ib	D
HR 3459	236.	5370.	2.08	0.424	0.464	2.609	0.005	-2.3	-0.072	G1 Ib	D
HR 4166	177.	5475.	2.36	0.380	0.459	2.586	-0.028	-1.4	-0.129	G2.5 IIa	
HR 5143	166.	5190.	2.75	0.277	0.540	2.543	-0.023	+0.2	-0.113	G5 II:	
HR 5165	253.	5430.	2.37	0.480	0.416	2.591	0.069	-1.7	-0.135	G0 Ib-IIa	
HR 6144	330.	7400.	1.80	1.509	2.277		0.169	-5.3	0.000	A7 Ib	pAGB?
HR 6536	117.	5160.	1.86	0.323	0.524	2.598	0.016	-2.6	-0.359	G2 Ib-IIa	D
HR 6978	649.	6000.	1.70	0.780	0.383	2.636	0.020	-4.4	0.075	F7 Ib	
HR 7014	1000.	6760.	1.66	1.429	2.043		0.226	-5.8	0.195	F2 Ib	
HR 7094	855.	6730.	1.75	1.208	1.460	2.711	0.227	-5.2	-0.026	F2 Ib	
HR 7264	156.	6590.	2.21	1.025	0.242	2.701	0.042	-3.2	-0.140	F2 II	D,S
HR 7387	880.	6700.	1.43	1.406	1.976	2.715	0.189	-6.7	0.015	F3 Ib	D
HR 7456	370.	5550.	2.06	0.459	0.421	2.611	0.087	-2.2	-0.143	G0 Ib	D
HR 7542	376.	5750.	2.15	0.605	0.426	2.633	0.185	-2.2	0.017	F8 Ib-II	pAGB?
HR 7770	960.	6180.	1.53	0.930	0.864	2.665	0.329	-5.4	0.080	F5 Ib	D
HR 7796	562.	5790.	1.02	0.818	0.425	2.645	0.026	-6.6	0.234	F8 Ib	V,S
HR 7823	1010.	6760.	1.92	1.294	1.674	2.729	0.219	-4.7	0.000	F1 II	
HR 7834	235.	6570.	2.32	1.022	0.259	2.691	0.060	-3.1	-0.078	F5 II	V
HR 7847	1040.	6290.	1.44	1.022	1.044	2.684	0.295	-5.9	0.077	F5 Iab	
HR 8232	165.	5490.	1.86	0.537	0.481	2.600	0.024	-3.3	0.076	G0 Ib	D
HR 8313	283.	4910.	1.58	0.203	0.721	2.593	-0.032	-2.8	-0.069	G5 Ib	V
HR 8412	284.	5280.	2.35	0.255	0.618	2.596	0.024	-1.0	-0.066	G5 Ia	D
HR 8414	161.	5210.	1.76	0.386	0.562	2.596	0.002	-3.1	0.020	G2 Ib	D
HR 8692	413.	4960.	1.90	0.210	0.662	2.597	-0.008	-1.8	-0.087	G4 Ib	

Comments code: V-variable, D-Double, S- $uvby\beta$  from Simbad, pAGB?- possible post-AGB star, RRL- RR Lyrae, SB-Spectroscopic Binary.

Similar to  $[c_1]$  the five A-type stars and the K1 star HR 461 were not included. The standard deviation is 152 K and the correlation coefficient is  $R = 0.98$ .

In order to explore a possible colour dependence on the above calibrations, we have selected the dereddened colour  $(b - y)_0$ . To calculate the reddening for the F-G supergiants we used the calibration given in eq. 5 of Arellano Ferro & Parrao (1990) which provides  $E(b - y)$  from  $(b - y)$ ,  $c_1$  and  $m_1$  indices with an accuracy of about  $\pm 0.03$  mag. The colour excesses so calculated are given in column 8 of Table 1. Since most of these supergiants of low reddening, and given the scatter in the reddening calibration, some small negative values are expected. These negative values should be used as zero reddening. The resulting equations with the colour term included have slightly smaller standard deviations and higher correlation coefficients. They are of the form:

$$T_{\text{eff}} = 501.6(\pm 255.1)[c_1] - 1980.1(\pm 467.3)(b - y)_0 + 6252.0(\pm 367.0), \quad (3)$$

with the standard deviation being 129 K and the correlation coefficient  $R = 0.98$ . Or for the  $[m_1]$  index:

$$T_{\text{eff}} = 2244.0(\pm 958.6)[m_1]^2 - 2350.0(\pm 1407.1)[m_1] - 2244.0(\pm 454.7)(b - y)_0 + 7375.8(\pm 236.8). \quad (4)$$

with the standard deviation being 119 K and the correlation coefficient  $R = 0.99$ .

At this point it is important to remark that since Lyubimkov et al. (2010) used  $[c_1]$ , among other indeces, to estimate  $T_{\text{eff}}$ , the correlations in Figs. 1 and 2 are expected. The calibrations of Eqs 1 to 4 are naturally in the temperature scale of Lyubimkov et al. (2010). What it is offered here are functional relations that can be confortably used to estimate  $T_{\text{eff}}$  in F-G supergiants from the  $c_1$  photometry with comparable accuracies.

The  $H\beta$  index is also linearly correlated with the temperature. For the linear fit between  $H\beta$  and  $T_{\text{eff}}$ , the for the 47 F-G stars with  $H\beta$  in Table 1, the standard deviation is 234 K and the correlation coefficient is  $R=0.93$ . This calibration being of less quality than the four represented by eqs. 1 to 4, we have not illustrated it.

#### 4. THE $\log g$ CALIBRATION

Calibrations of the surface gravity in yellow supergiants and bright giants have been performed in

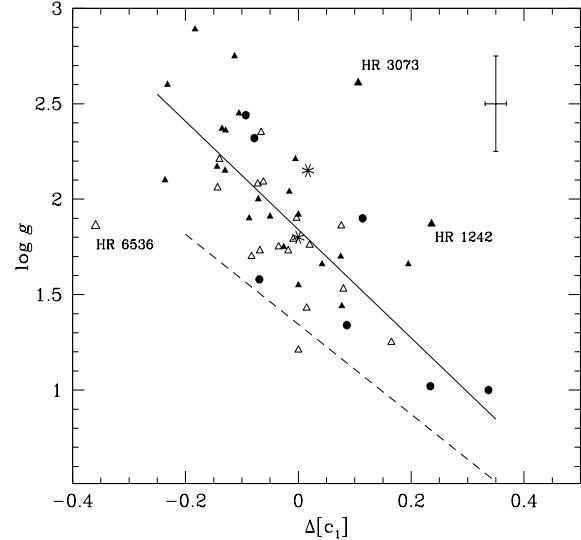


Fig. 3. Gravity dependence on the index  $\Delta[c_1]$ . Symbols are as in Fig. 1. Segmented line represents the calibration of Arellano Ferro & Mendoza (1993), which is 0.3-0.5 dex shifted towards lower gravities. See text for discussion. The error bars correspond to typical uncertainties of  $\pm 0.25$  dex and  $\pm 0.019$  mag in  $\log g$  and  $\Delta[c_1]$  respectively

the past by Gray (1991) and Arellano Ferro & Mendoza (1993). The strategy was to use the  $[m_1]$ - $[c_1]$  plane, on which the locus of a "standard line", determined from F-G Ib supergiants exclusively, was defined by Gray (1991). Then, a vertical parameter;  $\Delta[c_1] = [c_1] - [c_1](\text{standard line})$ , can be measured. It has been shown that  $\Delta[c_1]$  is correlated with  $\log g$ . Arellano Ferro & Mendoza (1993) used the spectroscopic gravities for 27 F-G supergiants given by Luck & Bond (1989) to calibrate the correlation. In this work we attempt a new calibration in the light of the new values of  $\log g$  given by Lyubimkov et al. (2010). The value of  $\Delta[c_1]$  for each star in the sample is given in column 10 of Table 1. Fig. 3 shows the  $\Delta[c_1]$  dependence on  $\log g$ . As before, the five A type and the K1 stars in the sample of Lyubimkov et al. (2010) have not been included. Among the F-G stars three outliers were noted in the  $\Delta[c_1]$ - $\log g$  plane; HR 1242 (F0 II) and HR 3073 (F1 Ia), both stars are non-variables, and the double star HR 6536. We have no ready explanation for their discordant position and they were ignored. The remaining 47 stars display a clear relationship and the straight line has the form:

$$\log g = -2.836(\pm 0.349)\Delta[c_1] + 1.841(\pm 0.040), \quad (5)$$

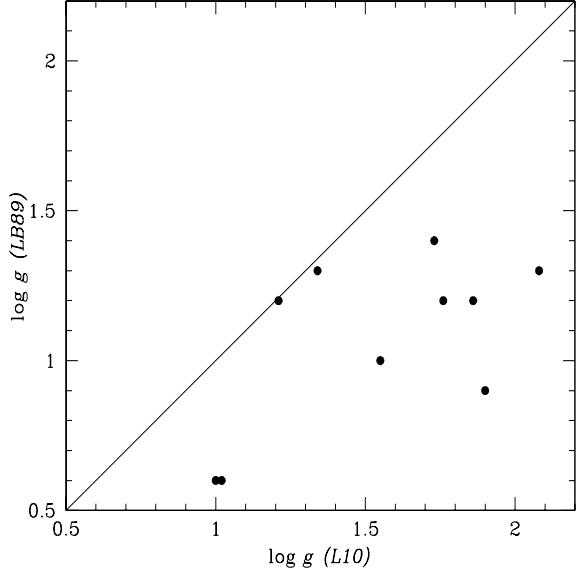


Fig. 4. Comparison of  $\log g$  values for ten stars in common between Lyubimkov et al. (2010) and Luck & Bond (1989). See text for discussion.

with the standard deviation being 0.267 dex and the correlation coefficient is  $R = 0.77$ .

Since there are evidences that  $\log g$  depends on  $T_{\text{eff}}$  for a given luminosity class (Straizys & Kuriliene 1981) we attempted to incorporate the colour term  $(b - y)_0$  but found it non significant.

Eq. 5, when compared with eq. 5 of Arellano Ferro & Mendoza (1993), it has smaller dispersion and a slightly higher correlation coefficient. However we should note that the present calibration indicates lower gravities by 0.3-0.5 dex for a given  $\Delta[c_1]$ . This invited a comparison of the gravities used by Arellano Ferro & Mendoza (1993), taken from Luck & Bond (1989), with the gravities used in the present work from Lyubimkov et al. (2010) and listed in Table 1. There are ten F and early G type stars in common and in Fig. 4 it is shown that the gravities of Luck & Bond (1989) are systematically smaller. Luck & Bond (1989) found that their spectroscopic gravities, obtained mostly from the ionization equilibrium condition on Fe I and Fe II lines, are systematically smaller by 0.3 dex than gravities derived via the membership of stars in clusters and their photometry. Similar discrepancies were found by Luck & Lambert (1985) for classical cepheids when spectroscopic gravities are compared with gravities obtained via PLC relationship. These authors forward a possible explanation in the fact that models built under the assumption hidrostatic equilibrium may not be a good representation for the extended atmospheres

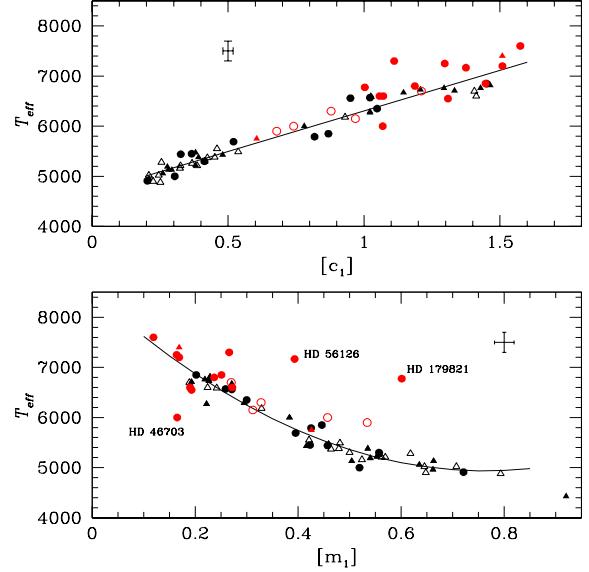


Fig. 5. Inclusion of postAGB and RV Tau stars in the  $T_{\text{eff}}$  calibrations. Black symbols are as in Fig. 1. Filled red circles are post-AGB stars and open red circles are RV Tau stars. The red triangle is the post AGB candidate star HR 7542 plotted as an asterisk in Figs. 1, 2 and 3.

of supergiant stars. The reader is referred to the detailed discussions on this point given in the above papers, and similar arguments might be invoked to explain the discrepancies displayed in Fig. 4.

##### 5. THE CASE OF post-AGB STARS

We often have wonder if the calibrations of physical parameters that have been worked out for young yellow supergiants would be equally valid for more evolved and less massive post-AGB stars of similar temperature and gravity. We found a few well known post-AGB and RV Tau stars in the catalogue of Stasińska et al. (2008) with reported values of effective temperature and gravity estimated by spectroscopic techniques, and with Strömgren photometry available in the Simbad database. These stars are listed in Table 2 and plotted in Fig. 5 with red symbols on the  $[c_1]$ - $T_{\text{eff}}$  and  $[m_1]$ - $T_{\text{eff}}$  planes of Figs. 1 and 2. The stars being rather faint, their spectral types may be difficult to determine with high accuracy, for this reason and for the sake of not cutting the sample too short, we included late A stars and one K0 star. For the  $[c_1]$  index the post-AGB and RV Tau stars follow very well the trend defined by the F-G supergiants and therefore it seems that the calibration is also valid for these types of stars stars. We have refrained from yet fitting the straight line with all points since the difference with eq. 1 would be negligible. For the

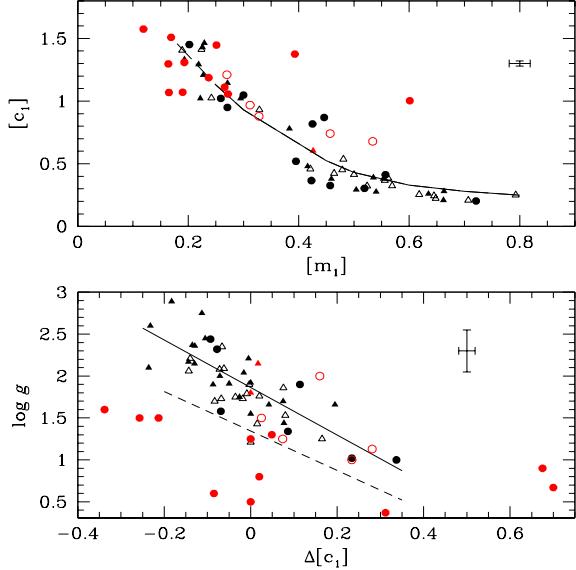


Fig. 6. Inclusion of postAGB and RV Tau stars in the  $\log g$  calibrations. The top panel shows the  $[m_1]$ - $[c_1]$  plane and the fiducial line defined by Gray (1991), relative to which the  $\Delta[c_1]$  parameter is measured. The lower panel shows the distribution of the different groups of stars in the  $\Delta[c_1]$ - $\log g$  plane. Symbols are as in Fig. 5. See text for discussion.

$[m_1]$  index the post-AGB's and RV Tau also follow the parabola of the F-G supergiants except for three stars HD 46703 (F7 IVw), HD 56126 (F5 Iab:) and HD 179821 (G5 Ia). HD 46703 has a spectral type of a subgiant which may explain its peculiar position, however for HD 56126 and HD 179821 we have no explanation at hand.

Let us now explore, in a similar way, the role of post-AGB stars on the  $\Delta[c_1]$ - $\log g$  plane. As for the of the young supergiants we started by plotting the stars on the  $[m_1]$ - $[c_1]$  from where one can estimate  $\Delta[c_1]$ . Fig. 6 illustrates both these planes. Except for the already noted howler stars HD 46703, HD 56126 and HD 179821, both the postAGB and RV Tau stars follow the distribution on the  $[m_1]$ - $[c_1]$  plane. However on the  $\Delta[c_1]$ - $\log g$  plane the post-AGB stars are at odds with the distribution of the supergiant stars. The five RV Tau stars (empty circles) seem to follow the supergiant trend rather well. With the available information we cannot say whether the post-AGB stars follow a completely different relationship or if this is a result of the gravities reported by Stasińska et al. (2008) being anomalously too small. In either case the relationship in eq. 5 is to be used only for the young supergiant stars.

## 6. COMMENTS ON THE DETERMINATION OF $M_V$

It would be desirable to posses a calibration that can predict the luminosity of young yellow supergiants given an observational parameter, such as for example a colour index. Since these stars are luminous they could be used as distance indicators. We have attempted before to calculate such calibration (Arellano Ferro & Parrao 1991; Arellano Ferro & Mendoza 1993), however an accurate result has been rather elusive. On the other hand a neat calibration of  $M_V$  from the intensity of the OI 7774 triplet, valid for a vast range of luminosities, was calculated by Arellano Ferro et al. (2003) which predicts  $M_V$  with an uncertainty of 0.38 mag.

The distances provided by Lyubimkov et al. (2010) could in principle serve to explore a calibration of  $M_V$  in terms of a photometric index. The absolute magnitudes listed in column 9 of Table 1 were calculated from the distances (column 2) and the reddenings (column 8). Since  $\Delta[c_1]$  is correlated with  $\log g$  one would expect a relationship between  $M_V$  and  $\Delta[c_1]$ . In Fig. 7 the plot of  $\Delta[c_1]$  vs.  $M_V$  is shown. Although a trend is clearly seen, the scatter is large ( $\sigma = 1.3$  mag). Inclusion of colour term,  $(b - y)_o$  does not improve the relationship ( $\sigma = 1.1$  mag).

We find of interest to consider a sample of F-G supergiants and 5 well documented post-AGB stars listed by Arellano Ferro et al. (2003) (their Table 3) for which their values of  $M_V$  have been calculated from the OI 7774 calibration.  $uvby\beta$  photometry for all these stars is available in the Simbad data base and then we could calculate their  $\Delta[c_1]$  parameter and plot them on Fig. 7 (red symbols) along with the F-G supergiants in Table 1. We see that both groups of stars follow the same trend and display a similar scatter. One can conclude from this that while the distances in Lyubimkov et al. (2010) are consistent with the absolute magnitudes predicted from the strengths of the OI 7774 feature in F-G supergiants, a reliable calibration of  $M_V$  in terms of a photometric index, for example  $\Delta[c_1]$ , is not foreseen.

## 7. CONCLUSIONS

New accurate values of  $T_{\text{eff}}$  and  $\log g$  (Lyubimkov et al. 2010) allow reliable functional relationships from Strömgren reddening free indices  $[c_1]$  and  $[m_1]$  that allow to predict the effective temperature and gravity in F-G supergiants. The temperature calibrations are given in eqs. 1 and 2 which predict the effective temperature with a standard deviation

TABLE 2

PHYSICAL PARAMETERS AND PHOTOMETRIC INDICES FOR A SAMPLE OF postAGB AND RV TAU STARS.

Star	$T_{\text{eff}}$ (K)	$\log g$ (dex)	$[c_1]$	$[m_1]$	$\Delta[c_1]$	Sp.T.	Comment
HD 46703	6000.	0.40	1.069	0.165	-0.463	F7 IVw	pAGB
HD 56126	7167.	0.67	1.375	0.393	0.700	F5 Iab:	pAGB
HD 95767	7300.	1.30	1.111	0.266	0.049	F3 II	pAGB
HD 107369	7600.	1.50	1.575	0.119	-0.213	A2 II/III	pAGB
HD 108015	6800.	1.25	1.187	0.237	0.000	F4 Ib/II	pAGB
HD 112374	6600.	0.80	1.057	0.272	0.020	F3 Ia	pAGB
HD 148743	7200.	0.50	1.509	0.169	0.000	A7 Ib	pAGB
HD 161796	6850.	0.37	1.447	0.251	0.312	F3 Ib	pAGB
HD 163506	6550.	0.60	1.309	0.193	-0.085	F2 Ibe	pAGB
HD 172481	7250.	1.50	1.297	0.164	-0.257	F2 Ia0	pAGB
HD 179821	6775.	0.90	1.003	0.601	0.675	G5 Ia	pAGB
HD 190390	6600.	1.60	1.071	0.190	-0.338	F1 III	pAGB
HD 170756	5900.	1.13	0.679	0.534	0.281	K0 III	RV Tau
AR Pup	6300.	1.50	0.879	0.328	0.025	F0 Iab	RV Tau
IW Car	6700.	2.00	1.211	0.270	0.160	A4 Ib/II	RV Tau
RU Cen	6000.	1.00	0.741	0.457	0.234	F7/F8;A4 Ib	RV Tau
EN TrA	6150.	1.25	0.968	0.312	0.074	F2 Ib	RV Tau

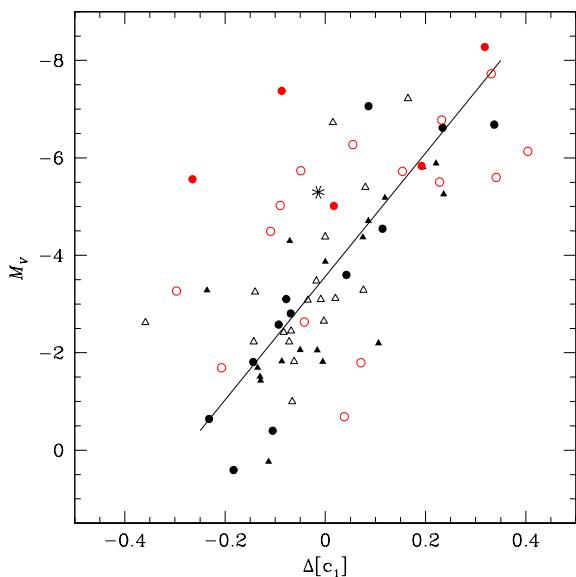


Fig. 7. Trend of  $M_V$  with  $\Delta[c_1]$ . Black symbols are as in Fig. 1. The red symbols correspond to a sample of F-G supergiants (open circles) and well documented postAGB stars (filled circles) taken from Arellano Ferro et al.'s. (2003) Table 3, and whose values of  $M_V$  were calculated from the OI 7774 feature.

of 152 K. If the reddening is available, alternative calibrations, given by eqs. 3 and 4 provide slightly smaller standard deviations of 129 and 119 K respectively. These calibrations are valid for the more evolved post-AGB of similar temperature and gravity. Given the fact that RV Tau stars are variables of large amplitude, it is rewarding to see that the five RV Tau stars included follow the temperature trends very closely. Perhaps their mean temperature and photometric indices are not too different from the temperatures reported by Stasińska et al. (2008) and the mean photometric indices calculated here.

The stellar gravity can also be predicted from the  $\Delta[c_1]$  index (Gray 1991) from the calibration of eq. 5 with an accuracy 0.28 dex. The colour term was found to be non-significant. This equation is valid for F-G yellow supergiants and very likely for RV Tau stars. However well known post-AGB stars of similar temperature and gravities (see Table 2) do not follow the calibration.

We have not been able to determine a reliable calibration that can predict the absolute magnitude  $M_V$  in F-G supergiant stars from photometric indices as accurately as from the strength of the OI 7774 feature.

Numerous comments and suggestions made by Prof. Sunetra Giridhar and of an anonymous referee are thankfully acknowledged. This work was

supported by DGAPA-UNAM grant through project IN114309. This research has made extensive use of the Simbad database operated at CDS, Strasbourg, France and of the NASA ADS Astronomy Query Form.

#### REFERENCES

Arellano Ferro, A., Parrao, L., 1990, A&A, 239, 205  
 Arellano Ferro, A., Mendoza, E.E., 1993, AJ, 106, 2516  
 Arellano Ferro, A., Rojo Arellano, E., González-Bedolla, S., Rosenzweig, P. 1998, ApJSS, 117, 167  
 Arellano Ferro, A., Giridhar, S., Rojo Arellano, E., 2003, Rev. Mex. Astron. Astrof., 39, 3  
 Bravo-Alfaro, H., Arellano Ferro, A., Schuster, W. H., 1997, PASP, 109, 958  
 Castelli, F., Kurucz, R.L., 2003, in Piskunov N.E., Weiss W.W., Gray D.F., eds, Proc. IAU Symp. 210, Modeling of Stellar Atmospheres. Poster A20, ASP, San Francisco, p. A20  
 Castelli, F., Kurucz, R.L., 2006, A&A, 424, 919  
 Gray, R.O., 1991, A&A, 252, 237  
 Lester, J.P., Gray, R.O., Kurucz, R.L., 1986, ApJS, 61, 509  
 Luck, R.E., Bond, H.E., 1989, ApJS, 71, 559  
 Luck, R.E., Lambert, D.L., 1985, ApJ, 298, 782  
 Lyubimkov, L.S., Lambert, D. L., Rostopchin, S. I., Rachkovskaya, T. M., Poklad, D. B., 2010, MNRAS, 402, 1369  
 Stasińska, G., Szczerba, R., Schmidt, M., Siódmiak, N., 2008, A&A, 450, 701  
 Straizys, V., Kurilene, G., 1981, ApSS, 80, 353  
 Yoss, K.M., 1961, ApJ, 134, 809